

Image analysis is driving a renaissance in growth measurement

Edgar P Spalding and Nathan D Miller

The domain of machine vision, in which digital images are acquired automatically in a highly structured environment for the purpose of computationally measuring features in the scene, is applicable to the measurement of plant growth. This article reviews the quickly growing collection of reports in which digital image-processing has been used to measure plant growth, with emphasis on the methodology and adaptations required for high-throughput studies of populations.

Address

University of Wisconsin-Madison, Department of Botany, 430 Lincoln Drive, Madison, WI 53706, United States

Corresponding author: Spalding, Edgar P (spalding@wisc.edu)

Current Opinion in Plant Biology 2013, **16**:100–104

This review comes from a themed issue on **Growth and development**

Edited by **Michael Scanlon** and **Marja Timmermans**

For a complete overview see the [Issue](#) and the [Editorial](#)

Available online 23rd January 2012

1369-5266/\$ – see front matter, © 2012 Elsevier Ltd. All rights reserved.

<http://dx.doi.org/10.1016/j.pbi.2013.01.001>

Introduction

Automated methods for measuring plant growth were in use by the end of the 19th century ([Figure 1](#)) but even then pioneers like Wilhelm Pfeffer (1845–1920) recognized the potential of early imaging techniques, ‘Photographic registration will probably be largely employed in the future, for series of pictures may be obtained which when placed in a kinematograph show the phases of several days’ or weeks’ growth in a minute or so’ [1]. In subsequent decades, researchers devised various photographic methods for studying growth. Computers were eventually brought to the task by digitizing video footage [2] or projecting photographic transparencies onto digitizing tablets [3,4]. As *Arabidopsis* with its great genetic advantages replaced traditional (and much larger) subjects such as oat coleoptiles, cucumber hypocotyls, and pea epicotyls, a millimeter ruler frequently could provide the resolution needed to answer the important questions at hand, such as whether the hypocotyl or root was longer or shorter than the wild type. Lack of need for high resolution coupled with the difficulty of achieving it with tiny *Arabidopsis* seedlings pushed the topic of growth measurement into something equivalent to the Dark Ages. Fortunately, the renaissance is well underway due to the advent of digital image acquisition and computational processing. The combination of high

resolution, accuracy, and throughput achievable with today’s sensors and computational technologies is allowing growth measurements to be compatible with large-scale, systems-style biology research.

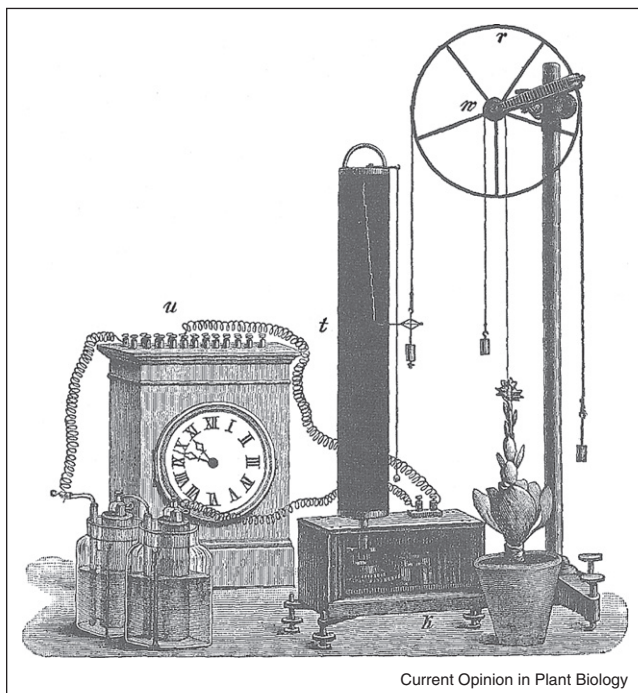
Basic image analysis

Nearly all machine vision solutions applicable to measuring plant growth from images depend fundamentally on segmentation and analysis of structure, two procedural stages that share a blurry border. Segmentation determines the boundaries of human recognizable components of the image that include the objects of interest. Structure analysis is concerned with characterizing curves, boundaries, pixel intensities and their differentials. Early computer vision practitioners recognized and addressed these general issues by devising algorithmic solutions to the challenges of finding lines, corners, and boundaries in digital images [5–11]. Such works continue to serve as the foundation for the image-analysis approaches to plant growth reviewed here. [Figure 2a](#) illustrates how segmentation and structure analysis can be combined to measure growth of an arbitrary structure shown at two time points and deliberately blended into the background. Segmenting the object of interest from the background can be achieved with algorithms ranging from those that detect the optimally discriminating threshold of pixel intensity based on the structure of frequency histograms [11] to those which assign each pixel a probability of belonging to an object based on Bayesian statistics [12], to those that utilize machine learning techniques such as support vector machines or neural networks [13–15]. Whatever method is used, the result is a set of object pixels from which the defining contour or boundary (black line in [Figure 2b](#)) can be determined. The boundary is used explicitly or implicitly to determine the midline of elongated objects (red lines in [Figure 2b](#)) such as seedling stems and roots. Each of the various midline-finding techniques which one can use depends on some determination of the point that lies equidistant between two opposite boundary positions.

Morphometrics

Midline length and the distribution of local curvature along it can give a very useful description of a biological structure such as a plant root or stem [16]. From a time series of images, the rate of change of these morphometric parameters can quantify growth and shape changes with resolution on the order of minutes and microns [17,18]. An important step in a midline-based growth measurement is detection of the correct termination point. One published solution for tracking growth of etiolated seedlings responding to light used a gap that is usually present

Figure 1



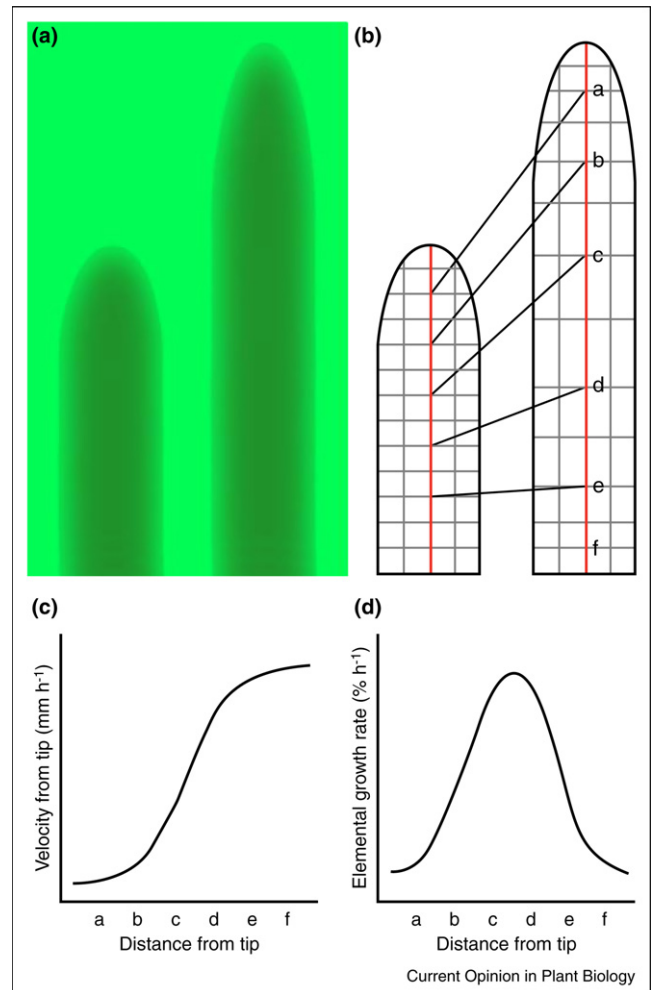
An auxanometer is a device for making automated measurements of growth. A figure of a late 19th century auxanometer taken from Wilhelm Pfeffer's classic textbook is shown [1].

at the base of the closed cotyledons as an identifiable point where the hypocotyl midline is terminated [19]. A technique that worked well for de-etiolated seedlings with opened cotyledons took advantage of a thickening of the hypocotyl at the cotyledonary node [20[•]]. A third technique that successfully quantified hypocotyl growth responses to ethylene used a local pattern-matching method to terminate the midline at a reproducible cotyledon location [21[•]]. These methods were either automatic or semiautomatic, which is necessary if the method is to replace standard manual methods and enable population genetic and systems-style studies. In the case of roots, which the object in Figure 2 reasonably well exemplifies, linear extrapolation of an apical subset of midline points intercepts the boundary at a point that has proven useful for termination [18]. The RootTrace tool terminates the midline at the tip by finding the last pixel in a progression having a sufficiently high posterior probability of belonging to the root object [22^{••}].

Kinematics

Whereas morphometrics is the study of geometric features, kinematics is the study of the internal material processes that create the geometry, namely cell production and expansion [23,24]. Kinematic analyses have

Figure 2



Schematic illustration of how morphometric or kinematic descriptions of growth are obtained from images. **(a)** An arbitrary shape having grown in length during a time step is deliberately made similar to the background to emphasize the fact that its separation from the background may not be trivial. **(b)** Successful segmentation defines the object's boundary (black outline) which aids in the determination of the midline (red line). The gray grid represents fiduciary marks, applied or endogenous, that if matched between images can allow a kinematic analysis of the behavior of the material comprising the object. **(c)** Velocity profile is obtained by determining how fast marks at each of the indicated positions moved away from the tip. **(d)** Elemental growth rate as a function of position is obtained by differentiating the curve in c.

shown plant growth to be a form of material flow, which has been tracked from sites of cell production by photographing growing organs marked with exogenous [3,4,25,26], or endogenous surface marks [27]. Figure 2b supposes a grid of features to be tracked within the object boundary to illustrate a kinematic analysis of growth. To an observer at the tip of the structure, point 'a' appears stationary over time because cells in that region are not expanding much. A point at location 'b' would move away

Download English Version:

<https://daneshyari.com/en/article/10869308>

Download Persian Version:

<https://daneshyari.com/article/10869308>

[Daneshyari.com](https://daneshyari.com)